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Simulation of Shrapnel to Aid in the Design of NIF/LMJ Target-Diagnostic Configurations

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Abstract Shrapnel fragments, produced when target/diagnostic components are impulse loaded, can reduce the lifetime of final optical components. We give simulations results of shrapnel generation in thin metal plates loaded by laser heating. We discuss two approaches to predicting the size and velocity distribution of the shrapnel fragments. The first uses the 2D LASNEX code to calculate energy absorption, shock propagation, and material response. The calculated strain rates combined with hydrodynamic quantities are used to determine properties of the fragments. The second uses the 1D DELPOR code to calculate energy absorption with the results coupled to the 3D HESIONE code to calculate dynamic fragmentation. We show results of varying the incident laser energy and the plate material. We compare with data obtained using low-density aerogel to capture shrapnel fragments.

I. Introduction

All target-diagnostic configurations that will be shot at the National Ignition Facility (NIF) and Laser MegaJoule (LMJ) must not produce unacceptable amounts of debris and shrapnel [1,2]. In this paper we restrict our attention to shrapnel fragments generated when target/diagnostic components are given an impulse loading by laser or x-ray emission. An important class of these components is thin metal plates used for shields, pin-hole arrays, etc. Impulse loading causes a shock to be sent into the metal and after reflection from the rear surface, the tensile stresses cause fragmentation to occur.

The final optical components exposed to shrapnel in the NIF and LMJ chambers are 1-cm thick fused silica main debris shields (MDS's) and ~1-mm thick borofloat disposable debris shields (DDS's). The relatively inexpensive DDS's will be placed in front of the MDS's for the majority of the shots. It is critical that there is not a large number of shrapnel fragments with sufficient velocity/size to penetrate or rear-surface spall the relatively thin DDS's. We discuss two approaches to modeling shrapnel generation and compare with recent experiments.

II. Continuum Hydrodynamic Simulations

In NIF and LMJ experiments, thin metal foils will be used as pin-hole arrays, backlighters, shields, etc. These foils will be exposed to impulse loading by laser and x-ray emission. As an example of our simulation capability, we discuss the heating of a 1-mm diameter, 250-μm thick Ta disk heated by a 4 ns, 2ω laser pulses with two incident energies of 40 simulation is above the yield strength for the material, we use the calculated strain rates to predict the size of the resulting fragments. We use different expressions depending of state of the material[3]. If the material is solid, the average size of the fragments is given by

$$S_{frag} = 0.333\ (Y/\rho)^{1/2}/\varepsilon^{o},$$

where Y is the yield strength (~5 x 10^9 dyne/cm^2 for Ta), ρ is the density, and ε^{o} maximum strain rate. If the material has been melted, we use

$$S_{frag} = 3.6\ (\gamma/\rho\varepsilon^{o2})^{1/3},$$

where γ is the surface energy (~3650 dyne/cm for Ta). Depending on the value of the strain rate, a given zone could produce a large number of small fragments or a portion of a large fragment. The velocity and direction of the fragments are taken from the zone where the fragments are produced. In Fig. 3 we give the calculated distribution of shrapnel fragments for the 200-J case as a function of size and velocity. We see that there is a trend of the smallest fragments having the largest velocity. In Fig. 4, we show the result of reducing the incident energy by a factor of 5. For this 40-J case, the size and velocity of the fragments are reduced.

III. Dynamic fragmentation

A second approach to modeling the generation of fragments is to use the 1D DELPOR code to calculate energy absorption and couple the results to the 3D HESIONE code to calculate dynamic fragmentation. It is very important that the same multiphase equation of state package and material parameters are used in the two codes. The two codes do have independent meshes. The Eulerian

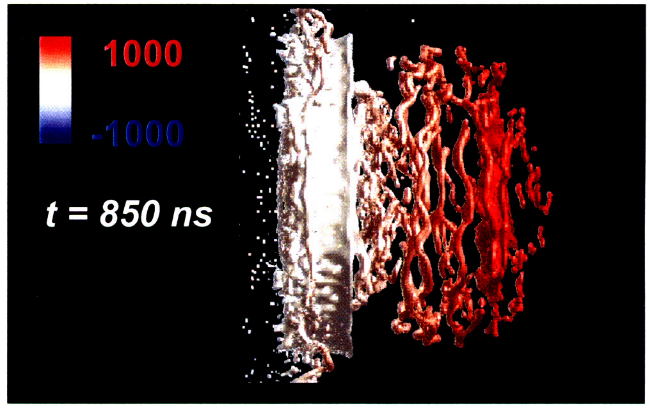

Figure 5 Simulation of Ta disk showing velocity of fragments incident energy of 220 J.

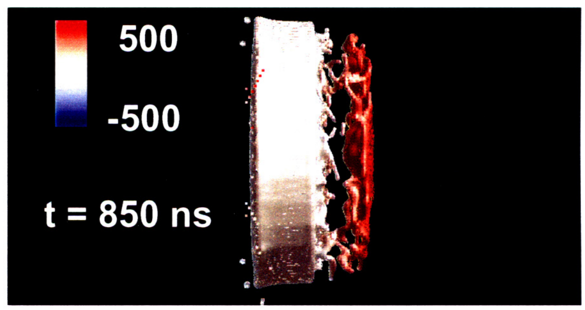

Figure 6 Same disk as in Fig. 5 but incident energy reduced to 70 J.

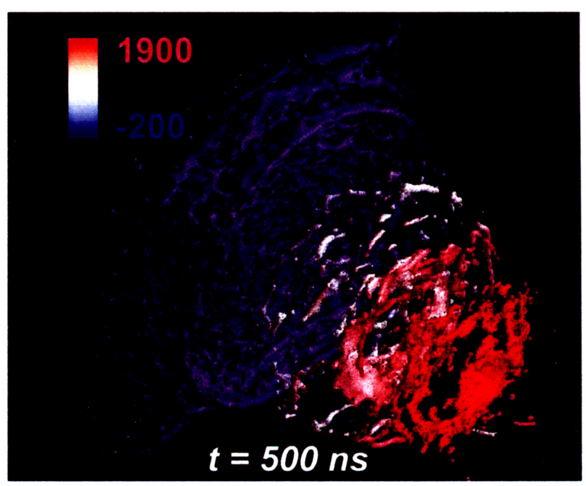

Figure 7 Simulation of Al disk with an incident laser energy of 40 J.

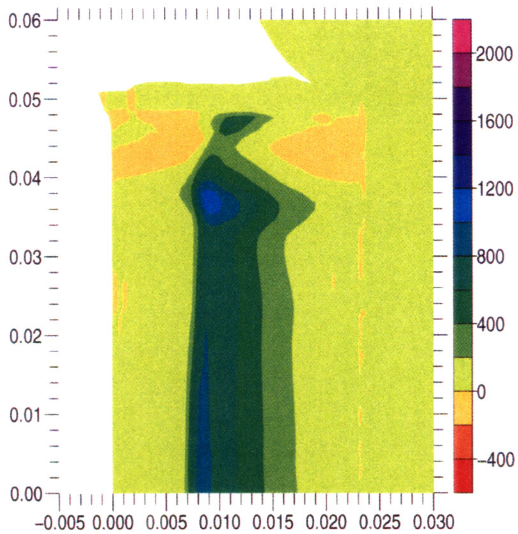

Figure 1 Pressure (kbars) in upper half of Ta disk 30 ns after laser pulse.

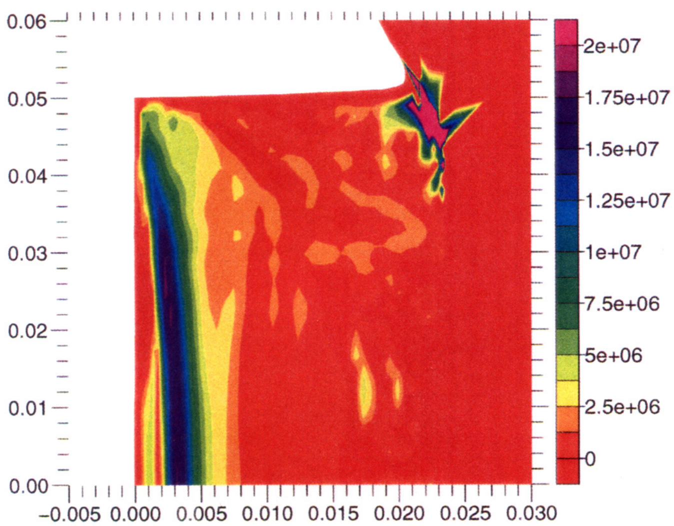

Figure 2 The strain rate ε^{o} (s^{-1}) in Ta disk 60 ns after the pulse.

and 200 J. The 2D LASNEX code calculates energy absorption and the resulting shock propagation into the material. In Fig.1 we give the pressure in the Ta 30 ns after the pulse is completed for the 200-J case. We show only the upper half of the disk with the laser incident on the right-hand side. At 30 ns the shock has broaden significantly

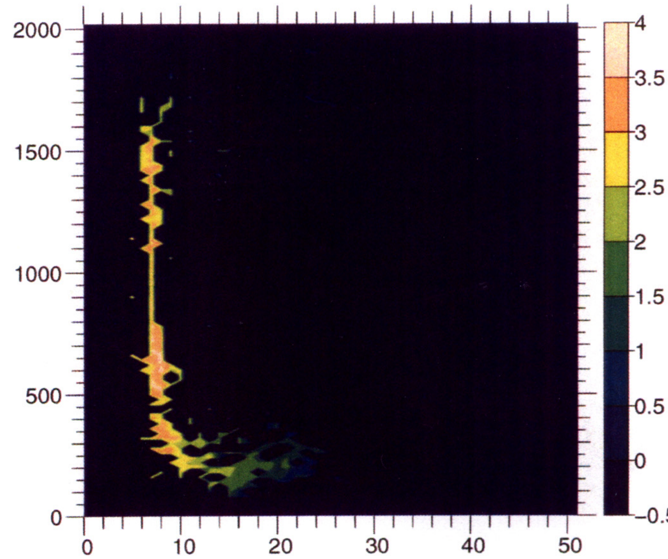

Figure 3 Log of the number of fragments as a function of size (μm) and velocity (m/s).

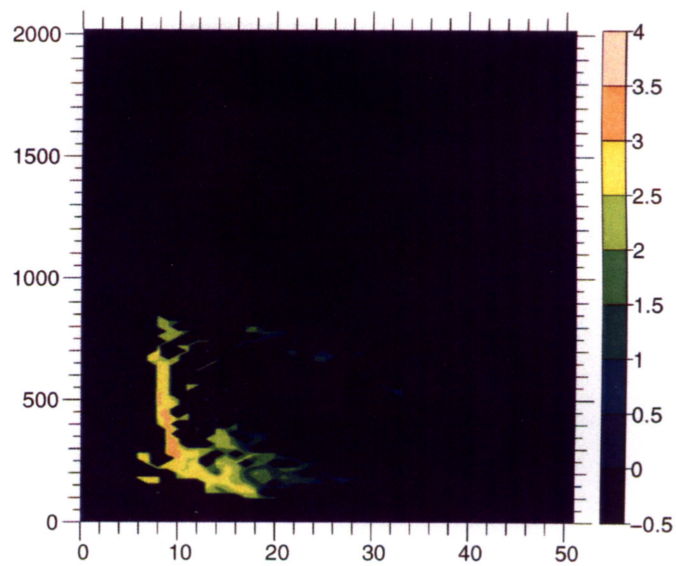

Figure 4 Same as Fig. 3, except incident energy being reduced factor of 5 to 40 J.

and has move approximately 2/3 of the way through the Ta. At approximately 50 ns the shock reaches the rear surface of the Ta and reflects putting the material into tension. The calculated strain rates are shown in Fig. 2 at 60 ns after the laser pulse. If the tension in a given zone in the hydrodynamic grid used in the HESIONE code limits the size of the smallest fragments that can be tracked. In the calculations presented here, we use 2 million 10x10x10 μm^3 cells. In Fig. 5, we show the breakup of a 1-mm diameter, 250-µm thick Ta disk heated by a 4.6 ns, 2ω laser pulse with an incident energy of 220 J. The velocities of the fragments at 850 ns are shown by the color of the fragments. The code calculates many solid fragments with maximum velocities of order 800 m/s. In Fig. 6, we show the effect of reducing the incident laser energy to 70 J. In this case, the spall is primarily in a single large chunk with a velocity of order 340 m/s. Finally, we show the effect of changing target material in Fig. 7. This simulation is for an Al disk with an incident energy of only 40 J. Due to Al having a much smaller yield strength as compared to Ta, we calculate a large number of fragments with maximum velocities of order 1850 m/s.

III Fragmentation Experiments

We have done a series of experiments on the HELEN laser at AWE, where metal disks are laser heated and the resulting fragments are captured in low-density aerogel[4]. From the penetration depth into the aerogel, the velocity of the fragments can be estimated. An example of this data is shown in Fig. 8. The data shown is for a 250-µm thick Ta disk with an incident 1 ns, 2ω pulse with an energy of 384 J. We see that the size/velocity distribution is similar to that shown in Fig.3, except for somewhat larger fragments. The sizes shown in Fig. 3, are the average size of the fragments in a given hydrodynamic zone. It is expected that there would be a Poission distribution of sizes for a given strain rate, which would result in larger

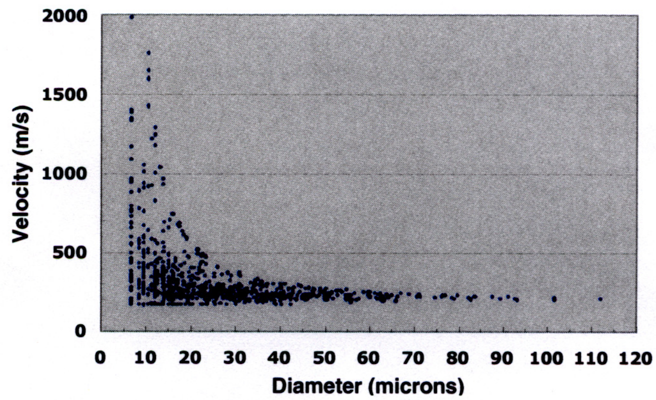

Figure 8 The size/velocity distribution of Ta fragments captured in aerogel.

fragments in the simulation. We are in the process of reducing the data using different materials, disk thickness, pulse durations, and laser energy. We will use this data to benchmark our simulations.

IV. Acknowledgments

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V. References

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